Solar Decathlon™

Battery Codes, Regulations, Best Practices and Contest-Specific Rules for the Solar Decathlon

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INTRODUCTION

This publication identifies and discusses codes, regulations, and best practices for battery use and installation as they relate to the specific rules of the Solar Decathlon. A battery system can be hazardous because it is a continuously “energized” source of electricity and contains corrosive electrolytes. Also, batteries can be heavy, can cause fires, and can produce explosive or corrosive gases. Solar Decathlon team members need to be aware of these inherent hazards to minimize the risk to themselves and the public when transporting, installing, maintaining, using, or replacing a battery. Although this publication focuses on lead-acid batteries, most of the information and discussion applies to all battery chemistries. Because this competition has a strong outreach component, its organizers are providing these guidelines to reinforce the importance of safety at this event.

Solar Decathlon

For eight days in the Fall of 2002, student teams will compete to capture, convert, store, and use enough solar energy to power our modern lifestyle. Solar Decathletes will be required to provide all the energy for an entire household, including a home-based business and the transportation needs of the household and business. During the event, only solar energy may be used to generate the power needed to compete in the ten Solar Decathlon contests.

The Solar Decathlon will be a living demonstration laboratory for consumers. Communication will play a key role in the competition. Each team will have a Web site, provide house tours, and create print materials that explain the design, engineering, and operation of their house as well as the products and technologies being used in the house.

Research and development endeavors in energy efficiency and solar energy technologies have improved our lives. The Solar Decathlon will not only have an immediate affect on consumers by educating them about solar energy and energy-efficient products, but it will also affect the future of our buildings. The competition will stimulate ideas and innovation in the next generation of researchers, architects, engineers, and builders.

Thus, Solar Decathlon homes should reflect sound building practices and safety. The public viewing these homes may choose to incorporate some of the features and technologies in their own homes. Since solar-powered homes will be new to many people, the homes need to demonstrate a safe photovoltaic (PV) system and battery. Although most people are familiar with automotive batteries, the batteries in the Solar Decathlon homes will be larger, and they are subject to additional regulations and considerations.

General Applicability and Interpretation

Therefore, this publication lists and discusses most of the codes, standards, and recommendations that apply to batteries typically used in solar-powered homes.

Although the list may look exhaustive, some codes, standards, or recommendations have been left out intentionally or may have been left out inadvertently. Also, state and local jurisdictions and the sponsoring school may have additional requirements beyond the international or national codes listed here.

Interpreting the codes, regulations, and recommendations is ultimately the responsibility of the individual Solar Decathlon teams and their institutions. In the Solar Decathlon Rules and Regulations, the organizers have established a minimum level of battery safety consistent with published codes, regulations, and recommendations. Individual teams or their sponsoring institution may add their own additional requirements.

Battery codes, regulations, and recommendations have only a minor impact on the home's energy usage. Batteries are emphasized here primarily because they represent an important safety issue. Solar Decathlon organizers encourage teams to make safety a priority throughout the competition.

In addition to safety, proper interpretation of codes, regulations, and recommendations can improve a battery's performance and extend its lifetime. Although the Solar Decathlon competition on the National Mall takes place over a brief period of time, a battery system should be designed, installed, and operated as if the house were to be occupied full time and the battery system lifetime needed to be maximized through proper operation and maintenance. The public will scrutinize the Solar Decathlon homes and the schools they represent, so all battery systems must be properly installed and operated.

Battery Terminology

Commonly accepted terms will be defined in order to interpret the codes and to discuss the issues within the context of the Solar Decathlon Rules and Regulations, and with other battery industry experts. The **cell** is the smallest *electrical* unit capable of producing voltage. In the lead-acid battery chemistry, the cell produces 2 V nominally. The **battery** consists of ALL the cells that are series or parallel connected.

Confusion begins when referring to the home's battery. Many of the codes and standards refer to "batteries" as the collection of individual batteries that comprise a battery. This publication, when discussing the Solar Decathlon competition, regulations, and suggested best practices, will refer to the house battery as the **battery bank** or **battery system**.

State-of-charge (SOC) is the percent of electrical energy stored in a battery compared to the manufacturer's rated capacity of the battery. A full battery has a 100% SOC and a discharged lead-acid battery has a 20% SOC. Most batteries are not fully discharged to 0% SOC even though the manufacturer's rated capacity is based on a full discharge. Depth-of-discharge (DOD) is the inverse of SOC. A fully charged battery has a 0% DOD while a discharged lead-acid battery has an 80% DOD.

Battery Chemistries

There are several electrochemical battery types available for solar-powered homes. The most common battery type is lead-acid, because of availability and cost. Other battery types that have been used are nickel-cadmium (NiCd), nickel-iron (NiFe), nickel metal hydride (NiMH) and lithium-ion. Each battery type has its own specific operating, transportation, cleanup, and disposal requirements. The battery manufacturer should supply this information along with a Material Safety Data Sheet (MSDS). While some of the discussion in this publication focuses on lead-acid batteries, most of the discussion is applicable to all types of batteries.

Most of the battery chemistries can be incorporated into vented or sealed battery configurations. Figure 1 shows the different types of lead-acid batteries. The vented (or flooded) configuration contains liquid electrolyte (either acid or base). During normal operation, electrolyte or electrolyte film may be present on top of the battery case due to the venting of hydrogen gas, overcharging or overfilling vented configuration batteries. Standard maintenance requirements for a vented battery includes visually checking the electrolyte level and adding distilled water if needed. In the vented configuration, electrolyte can spill out if the battery is tipped or if the case becomes damaged. A vented battery should come with spark arrestor vent caps for each cell. After-market hydrogen recombinant and spark arrestor vent caps may also be available to help reduce water loss. Check with the battery manufacturer before replacing any vent caps.

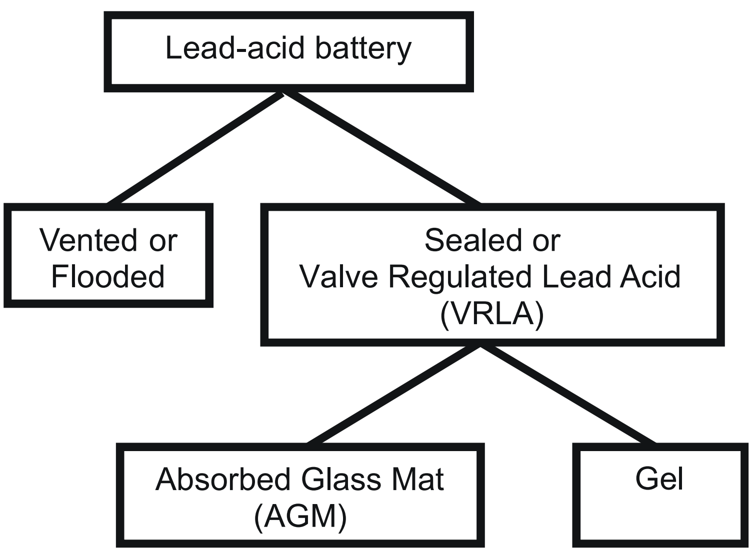

Figure 1. Different types of lead-acid batteries

The sealed (or valve-regulated lead-acid (VRLA)) battery configuration avoids many of the vented battery configuration's disadvantages by immobilizing or minimizing the electrolyte. Absorbed glass mat (AGM) batteries are different than gel batteries, even though both are sealed lead-acid batteries. An AGM battery immobilizes the electrolyte by absorbing the electrolyte into a fiberglass mat. A gel battery immobilizes the electrolyte by adding Silica Gel creating a semi-solid mass.

Under normal operating conditions in a sealed battery, the hydrogen gas that is generated during charging and discharging is recombined with oxygen inside the cell. Depending on the manufacturer, sealed batteries can usually be placed in any orientation (with the battery terminals on top or on the side). Some manufacturers claim that certain orientations of their sealed battery improve battery-recharging efficiency. Check with the manufacturer before placing a battery in an orientation different than as received. Sealed batteries are generally more convenient to install and operate even though the initial and operating costs may be higher.

Battery Hazards and Risks

A battery presents many hazards and risks—all of which can be minimized through proper design, installation, operation, maintenance, and disposal. A battery is always “energized”—there is no on/off switch. Even a battery that is “discharged” still contains a lot of energy. The corrosive electrolyte inside the battery can cause physical injuries to the user or additional damage to the battery if the electrolyte leaks out of the case, spills from the battery in an accident, or vents to the atmosphere. A battery can be heavy and awkward, especially if there is electrolyte on the outside of the case. Poorly designed battery rooms with limited space can hinder safe lifting and installation (or removal) of a battery. If improperly manufactured or maintained, a battery can cause a fire. Also, a fire near the battery can be started if the wiring and connections are improper or poorly maintained.

A vented or flooded battery will produce hydrogen gas during normal operation. A vented lead-acid battery with antimony-containing lead plates will produce more hydrogen than a battery with calcium-containing lead plates. A sealed or VRLA battery should contain all gases during normal operations. However, during abnormal circumstances, excess pressure inside the sealed battery will cause the battery to vent hydrogen gas. A sealed battery contains a one-way pressure relief vent that can release excess pressure from inside the battery case if the battery is overcharged or overheated, or if there is a battery failure. The total amount of hydrogen gas that can be generated from a vented or sealed battery can be similar but depends on the total amount of electrolyte inside the battery. The *rate* of hydrogen evolution is a function of the SOC, battery age, and current.

In summary, the risks to be considered when installing, utilizing, and maintaining a battery bank are:

- Explosion/flammability of hydrogen gas
- Electric shock and electric current hazards
- Acidic or caustic electrolyte spills/exposure
- Gravity related issues (such as battery lifting and batteries falling off racks due to seismic events)

CODES AND REGULATIONS

There are several national level code organizations that regulate the use of battery systems in building applications. The codes and regulations cited here come from the National Fire Protection Association (NFPA), International Fire Code Institute (IFCI), International Conference of Building Officials (IBCO), International Code Council (ICC) (which now includes IBCO Building Officials and Code Administrators International (BOCA) and Southern Building Code Congress International (SBCCI)), and the Occupational Safety & Health Administration (OSHA).

National Electrical Code 1999

NEC1999 articles 480 and 690-71, -72, -74 are relevant for storage batteries and batteries used in PV installations.

Article 480: Storage Batteries

NEC 480-1. Scope

The provisions of this article shall apply to all stationary installations of storage batteries.

NEC 480-2. Definitions

Nominal Battery Voltage. The voltage computed on the basis of 2 volts per cell for the lead-acid type and 1.2 volts per cell for the alkali type.

Sealed Cell or Battery. A sealed cell or battery is one that has no provision for the addition of water or electrolyte or for external measurement of electrolyte specific gravity. The individual cells shall be permitted to contain a venting arrangement as described in Section 480-9(b).

Storage Battery. A battery comprised of one or more rechargeable cells of the lead-acid, nickel-cadmium, or other rechargeable electrochemical types.

NEC 480-3. Wiring and Equipment Supplied from Batteries

Wiring and equipment supplied from storage batteries shall be subject to the requirements of this Code applying to wiring and equipment operating at the same voltage.

NEC 480-4. Grounding

The requirements of Article 250 shall apply.

NEC 480-5. Insulation of Batteries Not Over 250 Volts

This section shall apply to storage batteries having cells connected so as to operate at a nominal battery voltage of not over 250 volts.

(a) Vented Lead-Acid Batteries. Cells and multicompartment batteries with covers sealed to containers of nonconductive, heat-resistant material shall not require additional insulating support.

(b) Vented Alkaline-Type Batteries. Cells with covers sealed to jars of nonconductive, heat-resistant material shall require no additional insulation support. Cells in jars of conductive material shall be installed in trays of nonconductive material with not more than 20 cells (24 volts, nominal) in the series circuit in any one tray.

(c) Rubber Jars. Cells in rubber or composition containers shall require no additional insulating support where the total nominal voltage of all cells in series does not exceed 150 volts. Where the total voltage exceeds 150 volts, batteries shall be sectionalized into groups of 150 volts or less, and each group shall have the individual cells installed in trays or on racks.

(d) Sealed Cells or Batteries. Sealed cells and multicompartment sealed batteries constructed of nonconductive, heat-resistant material shall not require additional insulating support. Batteries constructed of a conducting container shall have insulating support if a voltage is present between the container and ground.

NEC 480-6. Insulation of Batteries of Over 250 Volts

The provisions of Section 480-5 shall apply to storage batteries having the cells connected so as to operate at a nominal voltage exceeding 250 volts, and, in addition, the provisions of this section shall also apply to such batteries. Cells shall be installed in groups having a total nominal voltage of not over 250 volts. Insulation, which can be air, shall be provided between groups and shall have a minimum separation between live battery parts of opposite polarity of 2 in. (50.8 mm) for battery voltages not exceeding 600 volts.

NEC 480-7. Racks and Trays

Racks and trays shall comply with (a) and (b).

(a) Racks. Racks, as required in this article, are rigid frames designed to support cells or trays. They shall be substantial and made of the following:

> 1. Metal, treated so as to be resistant to deteriorating action by the electrolyte and provided with nonconducting members directly supporting the cells or with continuous insulating material other than paint on conducting members, or
>
> 2. Other construction such as fiberglass or other suitable nonconductive materials

(b) Trays. Trays are frames, such as crates or shallow boxes usually of wood or other nonconductive material, constructed or treated so as to be resistant to deteriorating action by the electrolyte.

NEC 480-8. Battery Locations

Battery locations shall conform to (a), (b) and (c).

(a) Ventilation. Provisions shall be made for sufficient diffusion and ventilation of the gases from the battery to prevent the accumulation of an explosive mixture.

(b) Live Parts. Guarding of live parts shall comply with Section 110-27.

(c) Working Space. Working space about the battery systems shall comply with Section 110-26. Working clearance shall be measured from the edge of the battery rack.

NEC 480-9. Vents

(a) Vented Cells. Each vented cell shall be equipped with a flame arrester that is designed to prevent destruction of the cell due to ignition of gases within the cell by an external spark or flame under normal operating conditions.

(b) Sealed Cells. Sealed battery or cells shall be equipped with a pressure-release vent to prevent excessive accumulation of gas pressure, or the battery or cell shall be designed to prevent scatter of cell parts in event of a cell explosion.

Working Space

Article 480 references Sections 110-26 and 110-27. It is important to note that these sections apply to *all* electrical equipment, not just to batteries.

NEC 110-26. Spaces About Electrical Equipment

Sufficient access and working space shall be provided and maintained about all electric equipment to permit ready and safe operation and maintenance of such equipment. Enclosures housing electrical apparatus that are controlled by lock and key shall be considered accessible to qualified persons.

(a) Working Space. Working space for equipment operating at 600 volts, nominal, or less to ground and likely to require examination, adjustment, servicing, or maintenance while energized shall comply with the dimensions of (1), (2), and (3) or as required or permitted elsewhere in this Code.

> (1) Depth of Working Space. The depth of the working space in the direction of access to live parts shall not be less than indicated in Table 110-26(a). Distances shall be measured from the live parts if such are exposed or from the enclosure front or opening if such are enclosed.
>
> > Exception No. 1: Working space shall not be required in back or sides of assemblies, such as dead-front switchboards or motor control centers, where there are no renewable or adjustable parts, such as fuses or switches, on the back or sides and where all connections are accessible from locations other than the back or sides. Where rear access is required to work on de-energized parts on the back of enclosed

equipment, a minimum working space of 30 in. (762 mm) horizontally shall be provided.

Exception No. 2: By special permission, smaller spaces shall be permitted where all uninsulated parts are at a voltage no greater than 30 volts rms, 42 volts peak, or 60 volts dc.

Exception No. 3: In existing buildings where electrical equipment is being replaced, Condition 2 working clearance shall be permitted between dead-front switchboards, panelboards, or motor control centers located across the aisle from each other where conditions of maintenance and supervision ensure that written procedures have been adopted to prohibit equipment on both sides of the aisle from being open at the same time and qualified persons who are authorized will service the installation.

Table 110-26(a). Working Spaces

	Minimum Clear Distance (ft.)		
Nominal Voltage to Ground	Condition 1	Condition 2	Condition 3
0–150	3	3	3
151–600	3	31/2	4

Notes:
1. For SI units, 1 ft. = 0.3048 m.
2. Where the conditions are as follows:
Condition 1 — Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by suitable wood or other insulating materials. Insulated wire or insulated busbars operating at not over 300 volts to ground shall not be considered live parts.
Condition 2 — Exposed live parts on one side and grounded parts on the other side. Concrete, brick, or tile walls shall be considered as grounded.
Condition 3 — Exposed live parts on both sides of the work space (not guarded as provided in Condition 1) with the operator between.

(2) Width of Working Space. The width of the working space in front of the electric equipment shall be the width of the equipment or 30 in. (762 mm), whichever is greater. In all cases, the work space shall permit at least a 90 degree opening of equipment doors or hinged panels.

(3) Height of Working Space. The work space shall be clear and extend from the grade, floor, or platform to the height required by Section 110-26(e). Within the height requirements of this section, other equipment associated with the electrical installation located above or below the electrical equipment shall be permitted to extend not more than 6 in. (153 mm) beyond the front of the electrical equipment.

(b) Clear Spaces. Working space required by this section shall not be used for storage. When normally enclosed live parts are exposed for inspection or servicing, the working space, if in a passageway or general open space, shall be suitably guarded.

(c) Access and Entrance to Working Space. At least one entrance of sufficient area shall be provided to give access to the working space about electric equipment.

For equipment rated 1200 amperes or more and over 6 ft. (1.83 m) wide that contains overcurrent devices, switching devices, or control devices, there shall be one entrance not less than 24 in. (610 mm) wide and 6½ ft. (1.98 m) high at each end of the working space.

> Exception No. 1: Where the location permits a continuous and unobstructed way of exit travel, one means of access shall be permitted.
>
> Exception No. 2: Where the work space required by Section 110-26(a) is doubled, only one entrance to the working space is required. It shall be located so the edge of the entrance nearest the equipment is the minimum clear distance given in Table 110-26(a) away from such equipment.

(d) Illumination. Illumination shall be provided for all working spaces about service equipment, switchboards, panelboards, or motor control centers installed indoors. Additional lighting fixtures shall not be required where the work space is illuminated by an adjacent light source. In electrical equipment rooms, the illumination shall not be controlled by automatic means only.

(e) Headroom. The minimum headroom of working spaces about service equipment, switchboards, panelboards, or motor control centers shall be 6½ ft. (1.98 m). Where the electrical equipment exceeds 6½ ft. (1.98 m) in height, the minimum headroom shall not be less than the height of the equipment.

> Exception: Service equipment or panelboards, in existing dwelling units, that do not exceed 200 amperes.

(f) Dedicated Equipment Space. Equipment within the scope of Article 384, and motor control centers, shall be located in dedicated spaces and protected from damage as covered in (1) and (2).

> Exception: Control equipment that by its very nature or because of other rules of the Code must be adjacent to or within sight of its operating machinery shall be permitted in those locations.
>
> (1) Indoor. For indoor installations, the dedicated space shall comply with the following.

a. Dedicated Electrical Space. The space equal to the width and depth of the equipment and extending from the floor to a height of 6 ft. (1.83 m) above the equipment or to the structural ceiling, whichever is lower, shall be dedicated to the electrical installation. No piping, ducts, or equipment foreign to the electrical installation shall be located in this zone.

Exception: Equipment that is isolated from the foreign equipment by height or physical enclosures or covers that will afford adequate mechanical protection from vehicular traffic or accidental contact by unauthorized personnel or that complies with b., shall be permitted in areas that do not have the dedicated space described in this rule.

b. Foreign Systems. The space equal to the width and depth of the equipment shall be kept clear of foreign systems unless protection is provided to avoid damage from condensation, leaks, or breaks in such foreign systems. This zone shall extend from the top of the electrical equipment to the structural ceiling.

c. Sprinkler Protection. Sprinkler protection shall be permitted for the dedicated space where the piping complies with this section.

d. Suspended Ceilings. A dropped, suspended, or similar ceiling that does not add strength to the building structure shall not be considered a structural ceiling.

(2) Outdoor. Outdoor electrical equipment shall be installed in suitable enclosures and shall be protected from accidental contact by unauthorized personnel, or by vehicular traffic, or by accidental spillage or leakage from piping systems. The working clearance space shall include the zone described in Section 110-26(a). No architectural appurtenance or other equipment shall be located in this zone.

NEC 110-27 Guarding of Live Parts.

(a) Live Parts Guarded Against Accidental Contact. Except as elsewhere required or permitted by this Code, live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by approved enclosures or by any of the following means.

1. By location in a room, vault, or similar enclosure that is accessible only to qualified persons.

2. By suitable permanent, substantial partitions or screens arranged so that only qualified persons will have access to the space within reach of the live parts. Any openings in such partitions or screens shall be sized and located so that persons are not likely to come into accidental contact with the live parts or to bring conducting objects into contact with them.

3. By location on a suitable balcony, gallery, or platform elevated and arranged so as to exclude unqualified persons.

4. By elevation of 8 ft. (2.44 m) or more above the floor or other working surface.

(b) Prevent Physical Damage. In locations where electric equipment is likely to be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage.

(c) Warning Signs. Entrances to rooms and other guarded locations that contain exposed live parts shall be marked with conspicuous warning signs forbidding unqualified persons to enter.

FPN*: For motors, see Sections 430-132 and 430-133. For over 600 volts, see Section 110-34.

*FPN = Fine Print Notes denoted by FPN are explanations and are not mandatory rules.

PV Connected Batteries

Part H. Storage Batteries of Article 690 discusses requirements of battery banks that are connected to photovoltaic systems. The relevant sections are:

NEC 690-71. Installation

(a) General. Storage batteries in a solar photovoltaic system shall be installed in accordance with the provisions of Article 480. The interconnected battery cells shall be considered grounded where the photovoltaic power source is installed in accordance with Section 690-41, Exception.

(b) Dwellings.

1. Storage batteries for dwellings shall have the cells connected so as to operate at less than 50 volts.

Exception: Where live parts are not accessible during routine battery maintenance, a battery system voltage in accordance with Section 690-7 shall be permitted.

2. Live parts of battery systems for dwellings shall be guarded to prevent accidental contact by persons or objects, regardless of voltage or battery type.

FPN: Batteries in solar photovoltaic systems are subject to extensive charge-discharge cycles and typically require frequent maintenance, such as checking electrolyte and cleaning connections.

(c) Current Limiting. A listed, current-limiting, overcurrent device shall be installed in each circuit adjacent to the batteries where the available short-circuit current from a battery or battery bank exceeds the interrupting or withstand ratings of other equipment in that circuit. The installation of current-limiting fuses shall comply with Section 690-16.

NEC 690-71. Part (b) 2., appears to be an extension of 110-27, which requires the guarding of live parts for batteries a requirement for *all* battery systems in photovoltaic installations.. For batteries, a removable plexiglass cover over the battery terminals would provide adequate protection and prevent accidental contact by persons or objects.

NEC 690-72. Charge Control

Equipment shall be provided to control the charging process of the battery. Charge control shall not be required where the design of the photovoltaic source circuit is matched to the voltage rating and charge current requirements of the interconnected battery cells, and the maximum charging current multiplied by 1 hour is less than 3 percent of the rated battery capacity expressed in ampere-hours or as recommended by the battery manufacturer. All adjusting means for control of the charging process shall be accessible only to qualified persons.

FPN: Certain battery types such as valve-regulated lead-acid or nickel cadmium can experience thermal failure when overcharged.

NEC 690-74. Battery Interconnections

Flexible cables, as identified in Article 400, in sizes No. 2/0 and larger shall be permitted within the battery enclosure from battery terminals to nearby junction box where they shall be connected to an approved wiring method. Flexible battery cables shall also be permitted between batteries and cells within the battery enclosure. Such cables shall be listed for hard service use and identified as moisture resistant.

Uniform Fire Code 1997

Uniform Fire Code 1997 Article 64: Stationary Lead-Acid Battery Systems contains information that could apply to a residential installation; however, this code is mainly a commercial code. This article applies to stationary lead-acid systems having a liquid capacity of more than 100 gallons (the International Fire Code 2000 reduces this quantity to 50 gallons). It also states that stationary lead-acid battery systems with an individual capacity greater than 20 gallons shall comply with Article 80. Some of the more relevant sections of Article 64 are as follows:

UFC 6404.2 Safety Venting

Batteries shall be provided with safety venting caps.

UFC 6404.3 Occupancy Separation

In other than Groups A, E, I and R Occupancies, battery systems shall be located in a room separated from other portions of the building by a minimum one-hour fire-resistive occupancy separation. In Groups A, E, I and R Occupancies, battery systems shall be located in a room separated from other portions of the building by a two-hour fire-resistive occupancy separation.

UFC 6404.4 Spill Control

Each rack of batteries, or group of racks shall be provided with a liquid-tight 4-inch (101.6mm) spill control barrier which extends at least 1 inch (25.4mm) beyond the battery rack in all directions.

UFC 6404.5 Neutralization

An approved method to neutralize spilled electrolyte shall be provided. The method shall be capable of neutralizing a spill from the largest lead-acid battery to a pH between 7.0 and 9.0.

UFC 6404.6 Ventilation

Ventilation shall be provided in accordance with the Mechanical Code and the following:
The ventilation system shall be designed to limit the maximum concentration of hydrogen to 1.0 percent of the total volume of the room in accordance with nationally recognized standards, or
Continuous ventilation shall be provided at a rate no less than 1 cubic foot per minute per square foot (5.1 m^3/s per m^2) of floor area of the room.

UFC 6404.7 Signs

Doors into rooms or buildings containing stationary lead-acid battery systems shall be provided with approved signs. The signs shall state that the room contains lead-acid battery systems, that the battery room contains energized electrical circuits and that the battery electrolyte solutions are corrosive liquids.

UFC 6404.8 Seismic Protection

Battery systems shall be seismically braced in accordance with the Building Code.

UFC 6404.9 Smoke Detection

An approved automatic smoke detection system shall be installed in such areas and supervised by an approved central, proprietary or remote station service or local alarm which will give an audible signal at a constantly attended location.

UFC1997 Article 64 references Article 80 as an alternate method to show compliance. Article 80: Hazardous Materials is a rather lengthy section and will not be discussed here. UFC1997 also references the Building Code for seismic protection in regards to battery racks. For more information on this topic please review Uniform Building Code 1997 (UBC1997) Section 1634: Nonbuilding Structures for methodology on determining design loads for a battery rack.

International Fire Code 2000

The international code series is the evolution of the Uniform codes. The IFC2000 contains Section 608 Stationary Lead-Acid Battery Systems. This section reads similar to the UFC1997. The relevant section of this code is presented as follows:

Section 608: Stationary Lead-Acid Battery Systems

608.1 Scope

Stationary lead-acid battery systems having an electrolyte capacity of more than 50 gallons (189 L) used for facility standby power, emergency power or uninterrupted power supplies shall comply with this section.

608.2 Safety Venting

Batteries shall be provided with safety venting caps.

608.3 Room Design and Construction

Enclosure of a stationary lead-acid system rooms shall comply with the International Building Code. The battery systems are permitted to be in the same room with the equipment they support.

608.4 Spill Control and Neutralization

An approved method and materials for the control and neutralization of a spill of electrolyte shall be provided. The method and materials shall be capable of controlling and neutralizing a spill from the largest lead-acid battery to a pH between 7.0 and 9.0.

608.5 Ventilation

Ventilation shall be provided in accordance with the International Mechanical Code and the following:

1. The ventilation systems shall be designed to limit the maximum concentration of hydrogen to a 1.0 percent of the total volume of the room; or
2. Continuous ventilation shall be provided at a rate of not less than 1 cubic foot per minute per square foot ($1ft.^3/min/ft.^2$) [$0.0051m^3/(s*m^2)$] of the floor area of the room.

608.6 Signs

Doors into rooms or buildings containing stationary lead-acid battery systems shall be provided with approved signs. The signs shall state that the room contains lead-acid battery systems, that the battery room contains energized electrical circuits, and that the battery electrolyte solutions are corrosive liquids.

608.7 Seismic Protection

The battery systems shall be seismically braced in accordance with the International Building Code.

608.8 Smoke Detection

An approved automatic smoke detection system shall be installed in battery rooms in accordance with section 907.2.

Both UFC1997 and IFC2000 reference the “Mechanical Code” when discussing ventilation requirements. International Mechanical Code 2000 (IMC2000) has a section that deals with stationary lead-acid batteries.

International Mechanical Code 2000

Mechanical code ventilation requirements from the IMC2000 Section 502: Required Systems include:

IMC 502.1 General

Exhaust systems shall be provided, maintained, and operated as specifically required by this section and for all occupied areas where machines, vats, tanks, furnaces, forges, salamanders and other such appliances, equipment and processes in such areas, produce or throw off dust or particles sufficiently light to float in air, or which emit heat, odors, fumes, spray, gas or smoke, in such quantities so as to be irritating or injurious to health or safety.

IMC 502.3 Battery Charging Areas

Ventilation shall be provided in an approved manner in battery-charging areas to prevent a dangerous accumulation of flammable gases.

IMC 502.4 Stationary Lead-acid Battery Systems

Ventilation shall be provided for stationary lead-acid battery systems in accordance with this chapter and Section 502.4.1 or 502.4.2.

IMC 502.4.1 Hydrogen Limit

The ventilation system shall be designed to limit the maximum concentration of hydrogen to 1.0 percent of the total volume of the room.

IMC 502.4.2 Ventilation Rate

Continuous ventilation shall be provided at a rate of not less than 1 cubic foot per minute per square foot (cfm/ft.^{2}) [0.00508 $m^3/(s*m^2)$] of floor area of the room.

International Building Code 2000

Section 1621: Architectural, Mechanical and Electrical Component Seismic Design Requirements provides design requirements specifically for battery racks. Relevant sections include:

IBC 1621.3.13 Electrical Equipment Attachments and Supports

Attachments and supports for electrical equipment shall be designed to meet the force and displacement requirements of 1621.1.4 and 1621.1.5 and the additional requirements of this section. Electrical equipment designated as having an I_p^* greater than 1.0 shall itself be designed to meet the force and displacement requirements of 1621.1.4 and 1621.1.5 and the additional requirements.

Seismic effects that shall be considered in the design of other electrical equipment include the dynamic effects of the equipment, its contents and its supports. The interaction between the equipment and the supporting structures, including all other mechanical and electrical equipment, shall be considered. Where conduit, cable trays or similar electrical distribution components are attached to structures that could displace relative to one another and for seismically isolated structures where the conduit or cable trays shall be designed to accommodate the seismic relative displacement specified in Section 1621.1.5.

IBC 1621.3.13.1 Electrical Equipment

Electrical equipment designated as having an I_p* greater than 1.0 shall meet the following requirements:
1. Seismic impact between the equipment and other components shall be prevented.
2. The design load shall include the effects of loading on the equipment imposed by attached utility or service lines that are also attached to separate structures.
3. Batteries on racks shall have wrap-around restraints designed to prevent batteries from falling off the rack. Spacers shall be used between restraints and cells to prevent damage to cases. Racks shall have sufficient lateral load capacity.

* I_p = Component importance factor that is either 1.00 or 1.50, as determined in Section 1621.1.6

The IBC2000 seismic design load calculations for designing a battery rack are more straightforward than those of its predecessor UBC1997.

Occupational Safety and Health Administration

OSHA regulations regarding batteries are not as detailed as the codes above. The relevant section of the OSHA regulations is under (Standards: 29 CFR) Batteries and Battery Charging – 1926.441.

OSHA: 29 CFR Part 1926.441 (K)(a) Batteries and Battery Charging: Electrical – Safety Requirements for Special Equipment

(a)(1)
Batteries of the unsealed type shall be located in enclosures with outside vents or in well-ventilated rooms and shall be arranged so as to prevent the escape of fumes, gases, or electrolyte spray into other areas.

(a)(2)
Ventilation shall be provided to ensure diffusion of the gases from the battery and to prevent the accumulation of an explosive mixture.

(a)(3)
Racks and trays shall be substantial and shall be treated to make them resistant to the electrolyte.

(a)(4)
Floors shall be of acid resistant construction unless protected from acid accumulations.

(a)(5)
Face shields, aprons, and rubber gloves shall be provided for workers handling acids or batteries.

(a)(6)
Facilities for quick drenching of the eyes and body shall be provided within 25 feet (7.62 m) of battery handling areas.

(a)(7)
Facilities shall be provided for flushing and neutralizing spilled electrolyte and for fire protection.

OSHA: 29 CFR Part 1926.441 (K)(b) Batteries and Battery Charging: Electrical – Charging

(b)(1)
Battery charging installations shall be located in areas designated for that purpose.

(b)(2)
Charging apparatus shall be protected from damage by trucks.

(b)(3)
When batteries are being charged, the vent caps shall be kept in place to avoid electrolyte spray. Vent caps shall be maintained in functioning condition.

Department of Transportation

The U.S. Department of Transportation (DOT) classifies all electrochemical batteries as hazardous materials subject to regulation when transported in interstate commerce. Individual states generally adopt DOT regulations for intrastate commerce. All trucking companies and drivers should be familiar with the appropriate regulations for each state. Teams need to fully disclose to the driver and trucking company, all potentially hazardous materials (batteries, ethylene-glycol, cleaning solvents, paints, etc.) that are being transported.

Most of the DOT regulations relevant to the Solar Decathlon are contained in Title 49 of the Federal Code of Regulations (49 CFR). The Hazardous Materials Table in 49 CFR Part 172.101 lists different types of batteries. All lead-acid batteries, both vented (flooded) and sealed (VRLA), are considered "wet batteries." The section, 49 CFR Part 173.159, describes wet batteries and their packaging requirements. Generally, loads with wet batteries need to be placarded (the diamond-shaped warning label on trucks) which requires a driver with a Commercial Drivers License (CDL) with a Hazardous Material endorsement. There are two possible placarding exceptions mentioned below.

49 CFR Part 173.159 (d) defines "nonspillable" batteries that do not require a placard if all requirements in that subsection are met. The battery manufacturer can state compliance with (d)(2) – labeling and (d)(3) – the vibration and pressure differential tests. Get a copy of the certification from the battery manufacturer. Subsection (d)(1) states, "The battery must be protected against short circuits and securely packaged."

49 CFR Part 173.159 (e) could exempt flooded batteries from placarding if all four requirements are met. Subsection (e)(2) states, "The batteries must be loaded or braced so as to prevent damage and short circuits in transit." Subsection (e)(3) states, "Any other material loaded in the same vehicle must be blocked, braced, or otherwise secured to prevent contact with or damage to the batteries."

Compliance with the protecting, blocking, bracing, and preventing damage exceptions (d)(1), (e)(2) and (e)(3) in 49 CFR Part 173.159 is usually determined only after an accident. DOT inspectors will rarely give approval in advance. If there was an accident and the batteries shifted, broke or caused a fire, then you probably didn't meet the requirements. The problem can cascade further. Since you didn't meet the exception, the truck should have been placarded and driven by a driver with a CDL and a Hazardous Material endorsement.

Because the Solar Decathlon homes will have a battery system and will be transported in interstate commerce, all DOT regulations are applicable. If you hire a company to transport your home, you must fully inform the company and driver about the weight and type of batteries and provide an MSDS. The transportation company assumes responsibility for compliance with all shipping regulations. If you transport the home containing a battery system using your own driver, the driver (and maybe the school) assumes responsibility for meeting all DOT regulations.

Due to dynamic loading, a battery rack suitable for a stationary application will not be suitable for transportation. Teams should take special care in packing batteries for transportation. The battery system could be transported separately (from the house) and installed on site before the competition. After the competition, the battery system should be removed from the house for return transportation.

RECOMMENDED OR BEST PRACTICE STANDARDS

Institute of Electrical and Electronics Engineers

The Institute of Electrical and Electronics Engineers (IEEE) publishes consensus standards on a wide variety of topics. An IEEE standard is useful since it presents best practice recommendations and reflects a consensus within the industry.

Table 1. Listing of IEEE standards relevant to PV-powered homes with a battery

IEEE Standard	Title
450-1995	Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications
484-1996	Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications
485-1997	Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
928-1986	Recommended Criteria for Terrestrial PV Power Systems
929-2000	Recommended Practice for Utility Interface of PV Systems
937-2000	Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for PV Systems
1013-2000	Recommended Practice for Sizing Lead-Acid Batteries for PV Systems
1106-1995	Recommended Practice for Maintenance, Testing and Replacement of Vented NiCd Batteries for Stationary Applications
1115-2000	Recommended Practice for Sizing NiCd Batteries for Stationary Applications
1145-1999	Recommended Practice for Installation and Maintenance of NiCd Batteries for PV Systems
1187-1996	Recommended Practice for Installation Design and Installation of VRLA Batteries for Stationary Applications
1188-1996	Recommended Practice for Maintenance, Testing and Replacement of VRLA Batteries for Stationary Applications
1189-1996	Guide for Selection of VRLA Batteries for Stationary Applications
1374-1998	Guide for Terrestrial Photovoltaic Power System Safety
1375-1998	Guide for Protection of Stationary Battery Systems

IEEE standards written specifically for PV systems with a battery system are 928, 937, 1013, 1145 and 1374. The other standards may contain additional information that is useful for design and installation of any battery. IEEE Standard 929 is appropriate for grid-connected, utility-interactive PV systems.

SOLAR DECATHLON COMPETITION

National Park Service Requirements

National Park Service (NPS) is asking decathlon teams to adhere to OSHA standards.

Inspections

As with all codes, ultimately the code inspectors will determine that the code is met physically or by intent. Appropriate calculations for seismic design of racks and ventilation requirements for battery systems should be submitted for approval in advance. On-site inspections before the competition will be performed to ensure that health and safety requirements are met.

Performance Monitoring Requirements

Organizers expect teams to have a single physical location where the battery bank may be monitored with a watt transducer, shunt, or similar device. All electrical layouts that would have separate PV arrays serving separate battery banks are discouraged and must be approved by the rules and regulations committee.

SOLAR DECATHLON BATTERY-SPECIFIC RULES—AMENDED

The following Solar Decathlon Rules and Regulations have been amended. Compliance with these rules and regulations can be established through the following methods:

5.2.1. Safety—Each team is responsible for the safety of its house, car, and team members. Passing Inspection or implementing changes suggested in the team's structural report does not release the team from any liability. All houses, cars, and support vehicles must be maintained and operated safely at all times. A team will be disqualified and withdrawn from the Event at any time if they operate in an unsafe manner.

> 5.2.1.1. Each house will be required to have smoke detectors per IRC2000 requirements and a fire extinguisher with a minimum Underwriters Laboratory (UL) rating of 2A-10BC. All battery system rooms or rooms containing a battery system enclosure must have a smoke detector that is either audible from outside the room or has a remote indicator that is monitored by the team.
>
> 5.2.1.2. Each house must be equipped with proper personal protective equipment (PPE) (a minimum of chemical resistant gloves, apron and eye protection) in order to service their battery bank and as protection from any other thermal, electrical, mechanical or fluid system that presents any sort of hazard.

5.2.1.3. Each house must be equipped with the proper spill clean up kits for their battery bank or fluid systems. All batteries, regardless of placement on a rack or otherwise, must have a spill containment system in compliance with UFC1997 6404.4 Spill Control and 6404.5 Neutralization or IFC2000 608.4 Spill Control and Neutralization

5.4.1. Code Compliance—All houses must meet all applicable electrical requirements stated in the National Electric Code 1999 (NEC1999). Particular attention should be paid to Articles 690, 480, 445, 250, 400, 240 which references proper photovoltaic system design, storage batteries, generators, grounding, conductors & conductor ampacity ratings, overcurrent protection devices and warning labels, respectively. Specific alterations to the code requirements are included in Regulations—Event, Safety, Regulations—Electrical, Code Compliance, Battery Ventilation, Battery Stacking and Regulations—Energy Collection & Storage, Storage Batteries. Additional code requirements from UFC1997, IFC2000, IMC2000 and IBC2000 will supercede NEC1999 requirements as noted. Teams are also encouraged to read this publication: Wiles, John C. (2001). *Photovoltaic Power Systems and the National Electric Code: Suggested Practices*. Sandia Report SAND2001-0674.

5.4.2. Battery Enclosures—Battery systems must be fully contained in enclosures or rooms that remain within the 800-ft.^{2}-footprint. The cover must be locked so access to batteries inside the enclosure is limited to the team's decathletes. A battery system room will be permitted in lieu of a separate battery system enclosure if designed in accordance to UFC1997 Article 64: Stationary Lead-Acid Battery Systems or IFC2000 Section 608: Stationary Lead-Acid Battery Systems, as if the room contained corrosive liquids in excess of 100 gallons regardless of battery type.

5.4.3. Battery Ventilation—Battery system enclosures or rooms must be equipped with a passive or mechanical ventilation system per IFC2000 608.5 Ventilation, UFC1997 6404.6 Ventilation, or IMC2000 502.4 Stationary Lead-acid Battery Systems. Teams are required to provide either calculations or empirical evidence to show compliance. Such ventilation systems must exhaust or vent to the outdoors. The vent must be designed so wind cannot push hydrogen gas back down the vent. This requirement includes all battery types because any battery type will vent hydrogen gas under certain conditions.

5.4.4. Battery Stacking—Stacking the batteries is discouraged. If it is necessary to stack the batteries, a battery system rack must be used. The rack must meet the requirements of IBC2000 1621.3.13 Electrical Equipment Attachments and Supports. The rack must also meet the requirements of NEC1999 480-7 Racks and Trays. All racks containing flooded lead-acid batteries must provide 18 in. of clearance from the top of the battery or top of the battery post (whichever is greater) to the bottom of the next shelf for inspection and maintenance. All racks containing sealed batteries must provide adequate space for access with tools in order to verify tightness of terminal connections.

5.6.3. Storage Batteries—Teams are allowed to use battery systems in their house and car for storage of solar-generated energy. The battery system for the car must be the car manufacturer's original equipment. Battery data submittal shall be based on the manufacturer's published specifications provided by the team. Batteries must be available in sufficient quantities to be accessible to all participating teams. The battery modules may not be modified in any manner, including the addition of electrolyte additives, case modification, or plate addition, removal, or modification. However, teams are permitted to add distilled water to vented (flooded) lead-acid batteries for maintenance purposes.

5.6.3.1. Primary Batteries—The use of primary (non-rechargeable) batteries is limited to smoke detectors only.

5.6.3.2. Secondary Batteries—The use of secondary batteries (rechargeable) for items such as laptop computers is permitted provided that all laptops or similar devices used for Contest purposes are to be recharged from the house electrical system.

DISCUSSION, BEST PRACTICES AND SUGGESTIONS

While not directly related to a Solar Decathlon contest, battery system operation and maintenance, battery system locations, ventilation, enclosures, secondary containment, racks and proper protective apparel can affect overall safety and can impact the cost of your renewable system over its lifetime. In order to help teams meet code requirements, the following provides suggestions and outlines best practices when designing, installing, maintaining and utilizing a battery system.

Battery Operation and Maintenance Considerations

Something as mundane and easy to forget as battery maintenance can make or break the economics of your system. Pay careful attention to battery manufacturer recommendations, in terms of maintenance, to get the most out of your battery system.

The battery is the most significant element in your renewable energy power system that has variable efficiency. Depending on how well you take care of your batteries, you can realize round trip and life efficiencies that vary from as low as 20-30% to as high as 85-90%. Choosing the right charge/discharge strategy, selecting the correct battery system charger/charge controller, and utilizing a sound dispatch strategy for charging devices, meeting loads and auxiliary loads, are all important.

Operation

The renewable system designer/operator can control battery system operation to a large degree. How the designer/operator manages the battery system will have a strong effect on how well the battery system performs and how long it lasts. Proper management can also minimize safety risks.

Sometimes, it is difficult to find literature (from manufacturers, testing agencies, and academia alike) that describes exactly how to get the most out of a bank of batteries. Required parameters such as load profile, type of charging sources, resource profiles, dispatch strategy, dump load dispatch, etc., can vary from system to system. Therefore, this variability makes if difficult to understand each system well enough to optimize its battery operation strategy. There are, however, a few guidelines to keep in mind when developing your own operation strategy for your specific renewable energy system. They include:

1. Batteries reach peak round trip efficiencies when operated in the 50-85% SOC range.
2. Batteries cannot stay too long in the 75-90% SOC range without damage from sulfation (i.e. batteries need to be periodically fully charged, on a monthly or a quarterly basis).
3. Batteries kept at a high SOC (such as float or standby) can last a very long time. However, they will not realize much throughput in their lifetime.
4. Batteries repeatedly deeply discharged (to as low as 20% SOC) will realize a higher throughput but a shorter life (some manufacturers recommend discharging to 50% SOC to extend the battery life).

5. Manufacturers can/will often provide a curve that describes the depth of discharge/cycle life relationship. However, these curves are produced under fairly strict conditions that can be difficult to duplicate in the field. Treat these curves as a reference, not a warranty.
6. When there is a large amount of sunlight, it's probably better to run as many productive loads (pump water, chill milk, make ice) as you can to reduce the amount of energy that needs to be cycled through your battery system.
7. Avoid leaving batteries at a low SOC because batteries left at a low SOC can begin to sulfate within days.

Maintenance:

A well maintained and operated battery system can last many years. A poorly maintained and operated battery system can last a matter of weeks. Clearly it's easier to damage a battery system than it is to maintain it well. However, here is a list of checks that you can perform that will set you off in the right direction (most battery maintenance guides will include at least some of these checks):

Monthly:

1. Visually inspect the batteries (look for corrosion, damaged or missing caps, wet/damp spots around caps, cracks or leaks, signs of heaving posts, damaged cable leads, damaged terminals or connectors)
2. Physically check for loose connections (loose connections can lead to overheating and seriously affect battery efficiency)
3. Check the temperature at the battery terminal and look for batteries which deviate (thermally) from the norm
4. Take voltages of each battery (or cell if using 2 V cells) with and without current flowing and look for variation from the average. The cell voltage for a battery at open circuit that shows variation of as little as .15 V from the average can indicate a problem with that battery.
5. If using vented (flooded) batteries, take specific gravity measurements with the batteries at open circuit and look for any variations from the mean (a variation of as little as .020 can indicate a problem with that battery.
6. Also, if using vented (flooded) batteries, check fluid levels and fill as required (never allow the plates to become exposed to the air, use only distilled water, note which batteries are using more water and see if a pattern is developing, don't overfill with water, and never remove excess electrolyte solution)
7. Clean the tops of the batteries with a solution of 1/8 lb. baking soda per quart of warm water. Check with the battery manufacturer for approved detergents.

Quarterly: (in addition to the monthly checks)

1. Check connection resistance of inter-cell or inter-battery connectors (one step more than looking for loose connections) of 10% of the battery system

2. Measure the temperature of a random sample of 20% of the battery system

Annually: (in addition to monthly and quarterly checks)

1. Tighten all bolts to recommended torque
2. Record all connection resistances
3. Perform a capacity test

Optional: Thermographic scans (if this technology is available - even a camcorder with infrared imaging can do the trick) can provide an excellent insight into connection problems between batteries or cells.

If your system is equipped with a battery monitor (E-meter, Tri-Metric, Data Acquisition System (DAS), etc.), periodically check your round trip efficiencies. A drop in efficiency doesn't necessarily mean that your whole battery bank is dead. It is more likely that a few batteries or cells within the battery bank need to be replaced or charged separately. The sooner you replace or charge a battery or cell that is pulling an entire string down, the better. Battery banks tend to experience cascade type failures. A single bad battery or cell may accept less current causing the entire battery bank to accept less current.

These guidelines are only an example, and not an exemplary, maintenance guide. For a more comprehensive and thorough manual, contact the battery manufacturer; most battery manufacturers will provide a manual. Proper operation and maintenance does not guarantee that you will not experience some sort of failure in at least one of your batteries before the battery bank reaches its maximum expected life cycle. Yet, failure to maintain your battery bank all but guarantees a shortened and inefficient life for your batteries.

Good Battery System Locations

Sometimes the placement of a battery bank is an afterthought. This is not a good idea. As mentioned previously, proper operation and maintenance of your battery bank can make the difference in the economic viability of your renewable system. If a battery is not in an accessible location, proper maintenance probably will not happen, or if it does, it will be a nuisance every time you do it. Also, the environment surrounding your batteries (such as ambient temperature) can have a serious impact on the expected life of your batteries (overheating of batteries is one of the principal failure modes). Finally, the distance between your batteries and your principal load (typically the inverter) is directly related to your system efficiency (the closer the two are, the better).

Accessibility to the battery system increases the likelihood of its proper maintenance in a safe manner. Storing batteries in a mechanical crawl space or in an attic exposes batteries to elevated temperatures. This is probably one of the fastest methods to ruin a battery bank. A battery bank should be placed in an enclosure with a locked cover, or in a separate room with a door that can be locked.

Keep in mind the following when planning where to place your batteries:

- For vented (flooded) batteries, a minimum of 18 in. is required between the top of the battery or battery post (whichever is higher) and the structure above it, to allow safe inspection and routine maintenance. For sealed or VRLA batteries, a reasonable working distance is required.
- Minimize the distance between your batteries and your primary load (not only does the cable become expensive if you place your batteries far from your inverter, but the induction of your cables becomes a factor)
- Protect your batteries from overheating and from cell-to-cell temperature variations (don't place them in an attic or mechanical space that experiences high temperatures, don't place them in a dark box on the south side of your house, don't put them above or too near a heat source, etc.)
- Protect your batteries from cold and freezing. While a charged battery has a low freezing point, a cold battery has less available capacity.
- Make your battery system accessible for routine inspections and maintenance.
- Don't place your batteries directly below electronics, batteries can (and vented batteries do) emit corrosive gases which are damaging to many things, especially electronics.
- Don't locate your batteries where things will be inadvertently dropped on them.

Ventilation

Code references for this section: IMC2000 502.3 Battery-charging Areas & 502.4 Stationary Lead-acid Battery Systems, IFC2000 608.5 Ventilation, and UFC1997 6404.6 Ventilation.

Hydrogen gas presents a fire hazard in any battery system installation, regardless of battery type. Abnormal conditions, such as failure of the charge controller, may cause the PV charging current to flow unregulated into a fully charged battery system. In some cases, an individual cell on the battery fails and will act as a sink for the full battery system current. If any type of battery is overcharged it can emit significant amounts of hydrogen. The total volume could be less in some battery types since there is less electrolyte, but the maximum rate of gas evolution can be similar. For scenarios like these, Solar Decathlon regulations require a well-designed ventilation system. It may be necessary to design ventilation systems that go beyond a battery manufacturer's recommendations in order to meet the Solar Decathlon regulation that treats vented and sealed batteries equally with respect to ventilation rates.

Hydrogen gas is very light and has a strong propensity to disperse. However, it is also highly combustible and can ignite under a relatively wide range of conditions (batteries have been known to explode even in open air). Because vented or flooded batteries emit hydrogen gas, special care should be taken to avoid its accumulation. Sealed batteries certainly can, have, and do emit hydrogen gas when something goes wrong. Therefore, all systems must ventilate, either passively or actively, directly to the outside air.

Energy consumption from a mechanical ventilation fan is a small portion of a total building's energy consumption. One measure to reduce that amount of energy used by ventilation fans is to only turn the fans on during charging and discharging of the battery bank.

With either mechanical ventilation or natural ventilation systems, the ventilation system should be designed to prevent pressure differentials on or around the building from causing hydrogen gas to accumulate in the ventilation pipe, duct, or devices.

In choosing whether to use active or passive ventilation systems, consider the following:

Passive Ventilation:

This type of ventilation is acceptable if the battery system room or enclosure has an exterior wall or opens to the exterior of the building. For this type of ventilation to work, vents must be placed near the ceiling and near the floor.

Active Ventilation:

This type of ventilation is required if the battery system room or enclosure does not have an exterior wall or exterior access. Unless a DC brushless motor is used, the fan motor must be located in outside air and must push fresh air into the battery system room or enclosure. The ventilation fan should be activated when charging or discharging the battery system but must also be fail-safe. (A DC fan which runs directly from the batteries via a normally closed relay is an acceptable form of fail-safe. An AC fan that runs off the inverter is not).

Enclosures

Code references for this section: IFC2000 608.3 Room Design and Construction, 608.7 Seismic Protection, UFC1997 6404.3 Occupancy Separation, and 6404.8 Seismic Protection

A battery system enclosure is an appropriate means of separating your batteries from the rest of your electrical equipment, without building a separate room. This protects your electrical equipment from your battery gas emissions, minimizes the volume required to be ventilated (especially important if your electrical/battery system room does not have an exterior wall or exterior access), and prevents accidental contact with your batteries. Battery system enclosures must be constructed of acid-resistant materials (most plastics). A plastic bag draped over the tops of the batteries is not an enclosure. Whether or not an enclosure is used, all batteries should have some means of preventing accidental contact across the terminals (Plexiglas or rigid plastic covers are acceptable).

For inspection and maintenance purposes, the top of an enclosure should be at least 18 in. above the top of a battery or battery post (whichever is higher) unless the lid of the enclosure is hinged. A hinged lid on the enclosure will allow adequate access for maintenance and inspection and therefore can be in closer proximity to the top of a battery or battery post. It is recommended that the lid not touch the post or an electrical conductor under any circumstance.

Secondary Containment

Code references for this section: IFC2000 608.4 Spill Control and Neutralization and UFC1997 6404.4 Spill Control.

The purpose of secondary containment is both to capture any spills from watering vented or flooded cells as well as to capture any leaks from cracked or damaged batteries. Secondary containment systems should be sized according to IFC 608.4 Spill Control and Neutralization, so as to capture the entire contents of at least one battery. Secondary containment systems only work when constructed of sealed, acid-resistant material. A plastic bag is not considered secondary containment.

If racks are used, secondary containment should be used on each rack level. While a single pan at the lowest level may protect the environment, it does not protect the lower batteries from what goes on above.

Battery System Racks and Stacking

Code references for this section: NEC1999 480-7 Racks and Trays, IFC2000 608.7 Seismic Protection, UFC1997 6404.8 Seismic Protection and IBC 1621.3.13 Electrical Equipment Attachments and Supports.

If possible, battery system racks should be designed such that batteries are easily inspected, cleaned, and maintained. Most racks will have two levels and under certain circumstances may have three levels. As stated before, accessibility increases likelihood of proper maintenance. Keeping rack height minimized offers better accessibility. It also diminishes the likelihood of injury due to lifting batteries. For example, lifting a battery above a person's head in order to place it on the rack could be a dangerous situation.

Battery racks can provide an appropriate means of assembling many batteries within a smaller footprint; but care needs to be taken in the selection/design of the battery system rack. The rack levels must be spaced so as to allow easy and safe access to each battery level during routine inspection and maintenance. For vented batteries, a minimum of 18 in. is required between the top of a battery or battery post (whichever is higher) and the rack structure or ceiling above. This amount of space is required for safe inspection and maintenance. The rack spacing for sealed batteries can be less, depending on the terminal post locations and battery interconnections.

Placement of Disconnects

Code references for this section: NEC1999 Article 230 Part F, 690-14 Additional Provisions and 690-17 Switch or Circuit Breaker.

Battery system disconnects should be located as close to the exit as possible, should be as close to shoulder height as possible, and should be clearly labeled. Battery system disconnects, like fire extinguishers, should be readily accessible in case of an emergency. You do not want to enter deep into a room where batteries are experiencing catastrophic failure in order to actuate the battery system disconnects. In addition, battery system disconnects should be readily accessible for emergency response personnel.

Other Considerations

Spill clean-up kits should be on hand in the event of electrolyte spills. Proper personal protective equipment (PPE) should be available for dealing with leaking cells and cleanup of electrolyte.

Smoke alarms should be placed in the electrical space where batteries are contained. The smoke alarm should be loud enough or should have a remote location indicator so the alarm can be heard outside of the electrical space. Fire extinguishers rated for electrical/chemical fires should be on hand in the event of battery failure.

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